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Conservation of the endemic species of the Albertine Rift under future climate change

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ABSTRACT

The Albertine Rift region of Africa is one of the most biodiverse areas on the planet, with more threatened and endemic vertebrates than elsewhere on the continent. Many of the endemic species are confined to montane forest or alpine areas. We assessed impacts of loss of habitat to agriculture and predicted impacts from niche modelling of climate change to the endemic species of the Albertine Rift. Modelling species distributions for 162 endemic terrestrial vertebrates and plants, we estimated the average percentage of habitat already lost to agriculture at 38% across all species. However, of the remaining suitable habitat the average percentage protected is currently 46%, greatly increased by the recent establishment of Itombwe, Kabobo and Ngandja Reserves in eastern Democratic Republic of Congo from 30%. Species ranges in 2080 were estimated using climate models and predicted to lead to an average loss of an additional 75% of remaining suitable habitat across all species. An estimated 34 endemic species were predicted to lose > 90% of their current remaining suitable habitat. The percentage of the total suitable habitat protected in parks or reserves increases under future climate change to 56% because as ranges contract more of the remaining area occurs within existing protected areas. This indicates that the protected area coverage is reasonably well located for future climate change. Based on these data we estimate that 46% of the endemic species we assessed would qualify for threatened status on the global Red List.

1. Introduction

The Albertine Rift region, an ecoregion bordering the Democratic Republic of Congo, Uganda, Rwanda, Burundi and Tanzania, contains more endemic and globally threatened vertebrates than any other ecoregion on the African continent (Plumptre et al., 2007), and is part of the eastern Afromontane hotspot (Plumptre et al., 2004). Many of these species are found only on the mountains and massifs bordering Lake Albert in the north to Lake Tanganyika in the south. The Albertine Rift ranges in altitude from 600 m to 5100 m a.s.l and contains a wide variety of habitats from lowland rainforest, through medium altitude semi-deciduous rainforest, savanna grasslands and woodlands, Miombo woodland, *Oxytenanthera* bamboo, papyrus wetlands, *Carex* wetlands, montane forest, *Sinarundinaria* bamboo, *Hagenia-Hypericum* woodland, giant heather, giant *Senecio* and *Lobelia*, alpine moorland, up to bare rock at the summits of some mountains. It is this diversity of habitats which has contributed to the diversity and endemism of this region.

The conservation of the Albertine Rift started in 1925 with the establishment of Africa's first national park, the Virunga National Park in eastern Democratic Republic of Congo (Languy and de Merode, 2009). Subsequent protected areas were established in Uganda, Rwanda, Burundi and Tanzania in the 1930s and several of these were upgraded from reserves or hunting concessions to national parks in the 1950s and 1960s in Uganda and Tanzania and later in Rwanda and Burundi (Olupot et al., 2010). Much of the creation of the protected areas was aimed at protecting large mammals such as elephants (*Loxodonta africana*), hippopotamuses (*Hippopotamus amphibius*), mountain gorillas (*Gorilla beringei beringei*) and lions (*Panthera leo*), following observations of declining numbers due to human hunting (Willock, 1965). Recognition of the rich biodiversity of the region became apparent following surveys of Virunga National Park by Belgian scientists in the 1930s and 1940s (Languy and de Merode, 2009), and subsequent surveys of other sites from the 1960s onwards. More recently new forested national parks have been created such as Nyungwe National Park in Rwanda, and Bwindi Impenetrable National Park and Rwenzori Mountains National Park in Uganda, established from existing forest reserves.

The impacts of climate change on species and ecosystems are already evident in many ecosystems (Tingley et al., 2009; Pearce-Higgins et al., 2015). Even if CO_2 emissions were curtailed today, it would take

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centuries to reverse the impacts of the accumulated greenhouse gases (Solomon et al., 2009). It is estimated that climate change could surpass habitat destruction as a leading cause of extinction in species (Leadley et al., 2010). High latitude and high elevation ecosystems, and those with abrupt land use boundaries, are particularly vulnerable to predicted climate change (Parmesan, 2006; Sala et al., 2000). Temperature decreases by 5.2–6.5 °C with each 1000 m increase in altitude on mountains in the Tropics (Colwell et al., 2008) and consequently species can move upslope to maintain the same climate envelope with global warming (Anderson et al., 2013; Root et al., 2003). However, cases have already been documented where species were pushed up to a point where they could not move higher (Pounds et al., 1999).

Current climate forecasts suggest the Albertine Rift will become warmer and wetter in the future, with greater differences between wet and dry seasons and increasing likelihood of flash floods and landslides in the September–November wet period (Seimon et al., 2011; Seimon and Picton Phillipps, 2010; Picton Phillipps and Seimon, 2010). This information, together with advances in methods to undertake species distribution modelling (Elith et al., 2006, 2011; Phillips et al., 2004; Phillips et al., 2006) over the past 10 years, now makes an assessment of predicted climate change impacts on species in the Albertine Rift possible.

A preliminary trait-based assessment of species likely to be impacted by climate change in the Albertine Rift was made by Carr et al. (2013). They assessed 2358 species for traits that would likely make them susceptible to climate change and found 31 amphibians (28% of those assessed), 199 birds (20%), 31 freshwater fish (6%), 107 mammals (30%), 79 plants (39%) and 70 reptiles (42%) were likely to be most vulnerable to climate change. However, their study did not model species distributions to make predictions of the impacts of climate change from changes in niche suitability. Instead they used the IUCN Red List Extent of Occurrence polygons/range maps for estimating species distributions.

Conservation planning should incorporate the impacts of future climate change if species are to be conserved in the long term (Groves et al., 2012). The narrow range of habitats on mountains in the Albertine Rift is likely to make them vulnerable to climate change and here we use species distribution modelling to predict the probable impacts on endemic mammals, birds, reptiles, amphibians and plants. We assess how well the existing protected area network conserves species in the future and also assess the impact of the recent creation of three new protected areas in eastern Democratic Republic of Congo (DR Congo).

2. Materials and methods

2.1. Species records

We estimated the current and future distributions for 162 endemic species using location data. Species occurrence records for 119 species across 5 taxa: birds (27), mammals (18), plants (49), reptiles (11) and amphibians (14) were obtained from Wildlife Conservation Society biodiversity survey data, the Tanzanian mammal atlas, Global Biodiversity Information Facility (GBIF 2012: http://www.gbif.org), records of amphibian collections made by Mathias Behangana (Makerere University), Michele Menegon (Trento Science Museum) and Eli Greenbaum (University of Texas at el Paso), and small mammal collections by Julian Kerbis Peterhans (Chicago Field Museum). A total of 32,854 presence records were used in the modelling process, birds (8765), large mammals (17,345), small mammals (1448), plants (4473), reptiles (436) and amphibians (387) (see Fig. S1 (a–c) in Ayebare et al., 2018). The sample size used for model parameterization varied between 10 and 1200 localities per species.

For species that had fewer than 10 presence records we used the altitudinal ranges recorded for the species to estimate area of occupancy (AOO) within the extent of occurrence (EOO) or range provided by the IUCN Red List. We randomly selected point locations within this region to develop a species distribution model (see below). The distribution areas for 43 endemic species; birds (13), amphibians (15) and small mammals (15) were estimated using these randomly generated presence records from species' suitable altitude range maps.

2.2. Species distribution modelling

Maximum Entropy Species Distribution Modelling (hereafter 'Maxent', Maxent version 3.3.3e; Phillips et al., 2006), was used to estimate the current and future ranges for endemic and threatened species in the Albertine rift. Maxent uses a machine learning approach, and requires only species' presence data and environmental variables (Phillips et al., 2006). It has been shown to perform better than most other species distribution modelling methods (Phillips et al., 2006; Elith et al., 2006). Maxent makes inferences from incomplete information and estimates species' distributions by generating a probability distribution of maximum entropy (ie: closest to uniform), subject to constraints imposed by the information regarding presence records and the background information across the study area (Phillips et al., 2006; Elith et al., 2011). Maxent default parameters (Auto features, convergence threshold of 0.00001, maximum number of background points = 10,000, regularization multiplier = 1) were used to fit the models. However, about a third of the species that had few presence records (10 to 20) were fitted using hinge features (Elith et al., 2011). Hinge features are functions for piecewise linear splines and fit models closely related to Generalized Additive Models (Elith et al., 2011). Modelled species ranges are provided in Ayebare et al. (2018).

2.2.1. Current suitable habitat predictor variables

Climate layers at a spatial resolution of ~1 km^2 were obtained from the WorldClim database (Hijmans et al., 2005; http://www.worldclim.org). We selected 17 Worldclim variables relating to climate that are likely to influence the distribution of the birds, mammals, plants, reptiles and amphibians in the Albertine Rift. All the predictor variables were clipped to the area of interest and a pairwise Pearson correlation between predictor variables were obtained using ENMTOOLs (Warren et al., 2010; http://purl.oclc.org/enmtools). To minimize the effect of multi-collinearity and overfitting, only seven variables with less than (± 0.75) correlation were retained (See Table S1 in Ayebare et al., 2018).

2.2.2. Future predictor variables

To assess the impact of climate change on the future estimates of suitable habitat for endemic and threatened species in the Albertine rift, three General Circulation Models for the year 2080 under the A2a storyline were used;

i. CCCMA: CGCM2, simulated at the Canadian Centre for Climate Modelling and Analysis.
ii. CSIRO: MK2, simulated at the Commonwealth Scientific and Industrial Research Organization.
iii. HADCM3, simulated at the Hadley Centre for Climate Prediction and Research.

These models were developed under the framework of the Coupled Model Intercomparison Project Phase 3 (CMIP3) for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessement report (AR4).

There are four storylines (A1, A2, B1 and B2) in the Special Report on Emissions Scenarios (SRES) that describe images of the future in relation to a wide range of demographic, economic and technological driving forces and how greenhouse-gas (GHG) emissions are likely to vary (IPCC, Special Report on Emissions Scenarios, 2000). The A2a storyline describes a very heterogeneous world, that is self-reliant, with a high rate of population growth, slow economic development that is

regionally oriented and has slow technological change compared to other storylines (IPCC, 2007). The A2a scenario is pessimistic relative to other scenarios with regard to GHG emissions and is considered to be tracking the actual change in climate (de Pauw and Göbel, 2011). We modelled future suitable habitat, using the predicted values of the seven climate variables used for the current range assessment in 2080 for each of the three models. Where at least two of the three models predicted suitable habitat was identified as being suitable habitat in 2080.

2.2.3. Special report on emissions scenarios vs representative concentration pathways

This work was carried out in 2012 and used climate models that were the latest at that date. More recent climate models have been developed and in order to compare our results with these models we modelled a subset of the taxa, and assessed the differences in predictions for 20 birds under both sets of models. We assessed the impact of climate change on the future distribution of birds under the framework of the Coupled Model Inter-comparison Project Phase5 (CMIP5), using the Representative Concentration Pathways (RCP8.5) (Moss et al., 2008; IPCC, 2013). There are four Representative Concentration Pathways; RCP2.6, RCP4.5, RCP6, and RCP8.5 (Rogelj et al., 2012) that were adopted by the Intergovernmental Panel on Climate Change for the Fifth Assessment Report (AR5) (Moss et al., 2008; IPCC, 2013). These scenarios are based on anthropogenic forcings, in which Co_2 concentrations are higher for all RCPs in 2100 relative to the current Co_2 baseline of 1986–2005.

Under the Special Report on Emissions Scenarios we used the A2 storyline which has a median temperature increase of 3.9 °C compared to the highest Representative Concentration Pathway RCP8.5 that has a median temperature increase of 4.6 °C (See Table S2 in Ayebare et al., 2018). Three General Circulation Models for the year 2070 under CMIP5, RCP8.5 were used:

- ACCESS1.0: (Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology
- HadGEM2-CC (Hadley Centre for Climate Prediction and Research)
- CCSM4 (US National Center for Atmospheric Research)

The same General Circulation Models that were used under the Coupled Model Intercomparison Project Phase3, were considered for CMIP5 except for CGCM2, which was not available for downloading at the Worldclim website.

2.2.4. Estimating AUC and thresholds

Model accuracy for current and future predicted ranges was assessed by testing how well the model prediction differentiates between suitable and unsuitable habitat at varying thresholds using the area under the receiver operating characteristic curve (AUC) test statistic (Fielding and Bell, 1997; Freeman and Moisen, 2008). AUC is a threshold independent metric that represents how likely a random selection from a presence site is ranked compared to a random selection from an absence/pseudo absence site (Fielding and Bell, 1997; Phillips and Dudik, 2008). An AUC value of 0.5 indicates a model that performs no better than random while a model with perfect discrimination has a value of 1. Model outputs with AUC values ≥ 0.8, were selected for the final analysis (Manel et al., 2001). 75% of the occurrence records were used for training and 25% for testing the model. After assessing model accuracy, the final models for all the species were fitted using all occurrence records. To convert the predicted habitat suitability from a continuous logistic output format into a binary (presence/absence) output, the “maximum training sensitivity plus specificity” threshold rule was used (Liu et al., 2005; Freeman and Moisen, 2008).This threshold rule minimizes the mean error rate for positive observations and the error rate for negative observations (Freeman and Moisen, 2008) and has been recommended to be one of the better measures to identify thresholds (Liu et al., 2005; Freeman and Moisen, 2008).

2.3. Comparison of current range maps with IUCN EOO polygons

Modelled species range maps make an estimate of the area of occupancy (AOO) of a species and have been used for mapping species richness (Graham and Hijmans, 2006) and conservation planning (Guisan et al., 2013). The IUCN range polygons for each species that were used by Carr et al. (2013) measure the extent of occurrence (EOO) of most species and where they are more accurate EOO is often specified in the species description. EOO is measured by mapping the polygon that encloses all the observed locations of a species, and as such often includes habitat that is not suitable for the species. We compared the areas of habitat estimated for a species using both the EOO from the IUCN Red List assessments (IUCN, 2016) and AOO estimated from our models to assess the average reduction in range size when assessing AOO using species distribution models.

2.4. Loss of habitat to agriculture in current range

The predicted species' ranges represent the range of environmental gradients within which a species is predicted to be present. However, some of the suitable habitat has been modified by human activities already. To remove areas already modified, the GlobCover 2009 land cover map was re-classified into three land cover classes; water, other, and natural vegetation (ESA, 2010). The “other” class was characterized by agriculture areas, plantation forestry and human settlements. When exploring the GlobCover 2009 land cover map in ArcGis 9.3 we found that there were vegetation misclassifications in our study area. For example some of the high tropical forest reserves had been classified as mosaic vegetation/cropland. We edited the GlobCover 2009 landcover map by locking in areas we knew to be natural vegetation and using other landcover maps for the region to produce a final layer used for removing modified habitat from the species range maps.

After calculating the percentage range lost to agriculture of the current ranges we then calculated the percentage loss of remaining range to future climate change by 2080. This calculation assumed that there will be no more habitat conversion to agriculture in future, which is unlikely to be the case so estimates should be considered to be the minimum loss that might occur. Overlap between the current and future ranges (with converted habitat removed) was calculated by identifying where current and future predicted suitable habitat overlapped.

2.5. Testing our niche models with new data

The model predictions for current suitable habitat were field validated with surveys in a forest south of the Itombwe Reserve, in the North Balala region, where surveys of birds and plants were made at various elevations to assess whether the species observed fell within the predicted threshold ranges we had modelled. A conceptual framework of the full analysis is given in Fig. S2 (Ayebare et al., 2018).

3. Results

3.1. Results of tests of models

The 162 species distribution models were sent to experts for the various taxa for examination and in a few cases were re-modelled following these assessments by using masking to produce a final set of habitat suitability models. Tests of these models in the North Balala region indicated that for the 18 endemic birds and 14 endemic plant species that were detected (with several individuals across the altitude gradient), the accuracy of the models in predicting presence were 98% sensitivity and 2% omission for birds and 66% sensitivity with 34% omission for plants. This indicated that the models for birds were reasonably accurate but less so for plants, and the plants were remodelled with these additional data for the final analyses.

3.2. Comparison of range size of EOO vs AOO

In comparing our modelled ranges (AOO) for 58 species (birds, amphibians, reptiles, small mammals) where EOO was mapped or recorded on the IUCN Red List (IUCN, 2016) we found that on average range sizes were overestimated with the modelled AOO forming 55% of the EOO. Bird AOO was on average 56%, mammals 65%, reptiles 41% and amphibians 40% of the size of the EOO range. Many studies use the IUCN range maps for global assessments and it must be recognised that for many species, only EOO is mapped which we have shown greatly overestimates range size and suitable habitat. Some taxa such as mammals and birds have more accurate maps on the IUCN Red list and tended to be closer to the AOO predicted from modelling.

3.3. Loss of predicted suitable habitat to agriculture

Of the estimated 353,700 km^2 of the Albertine Rift region 106,300 km^2 or 30% has been converted to farmland or settlement already and 44,377 km^2 (an additional 4%) is made up of lakes. The predicted current range and loss to agriculture for each species was calculated (See Table S3 in Ayebare et al., 2018). Range sizes of species varied by more than an order of magnitude (Table 1). Of the modelled suitable habitat, 38% on average has already been lost to agriculture and settlements, although this varied greatly by taxon (Table 1). Most endemic species have lost habitat in the Albertine Rift region, although threatened endemic large and small mammals have been most affected, losing about 46% and 44% suitable habitat respectively. Some species have lost as much as 80–90% of their estimated suitable habitat already (Table 1; Table S3 in Ayebare et al., 2018).

3.4. Percentage of current suitable habitat in protected areas

Measures of the percentage of existing suitable habitat (removing habitat loss to conversion) currently within protected areas were calculated (See Table S3 in Ayebare et al., 2018) and summarised by taxon in Table 2. Calculations were made before and after establishment of the Itombwe, Ngandja and Kabobo Reserves (gazetted between June and December 2016 in eastern DR Congo). Across all taxa, on average 30% of current suitable habitat occurred in the old protected areas and addition of these three new protected areas increased this to 46% (Table 2).

3.5. Species richness across Albertine Rift

In order to quantify the richness of the predicted current distributions, we summed the threshold models for all taxa (birds, plants, mammals, amphibians, reptiles) to obtain an estimate of richness of endemic species and threatened endemic species across the Albertine rift (Fig. 1a and b). These results show that the higher species richness was found in the highland areas of the Albertine Rift (Rwenzori Mountains, Bwindi Impenetrable National Park, Virunga volcanoes, Nyungwe-Kibira National Parks, highlands of Kahuzi Biega National Park, and Itombwe and Kabobo massifs).

3.6. Impacts of future climate change

3.6.1. Estimated suitable habitat in 2080

Distributions for each species were obtained by combining binary outputs from the model projections based on the three GCMs. Of the 162 species that were modelled under current climate conditions 138 could be modelled into the future. For 23 species the models were poor (no model consensus among GCMS) and were not included. Individual species binary outputs were summed to produce maps of endemic species richness for future suitable habitat (Fig. 2a and b). These figures predict that the highest concentrations of the endemic species occur in the highest elevations of the Albertine Rift but that overall the numbers of endemic species at a site decline. Peak richness in the region was forecasted to drop from 99 to 85 for endemic species (Figs. 1a and 2a) and 17 to 13 for threatened endemic species (Figs. 1b and 2b).

To evaluate the extent to which climate change is likely to influence species suitable habitat, we compared the current distributions of each species with the projected future distribution in the year 2080 (See Table S3 in Ayebare et al., 2018). Even with no additional habitat loss, mean loss across all species was 69% of current remaining suitable habitat, and the average for each taxon varied between 68 and 80% loss by 2080 (Table 3). Seven species were forecasted to show an increased suitable habitat.

Thirty-four endemic species are at very high risk of range contraction, and are predicted to lose 90–100% of their current range. The endemic species that are likely to experience the highest risk (losing between 99% to 100% of their current range) from climate change impacts are: red-collared mountain babbler (*Kupeornis rufocinctus*) (99%), Kahuzi swamp shrew (*Crocidura stenocephala*) (99%), Willard's horseshoe bat (*Rhinolophus willardi*) (100%), *Embelia libeniana* (99%), *Psychotria palustris* (100%), and *Otiophora pauciflora* (100%) (See Table S3 in Ayebare et al., 2018). Threatened endemic species that are likely to lose between 90 and 100% of their current range include Grauer's rush warbler (*Bradypterus graueri*) (96%), green broadbill (*Pseudocalyptomena graueri*) (91%), yellow-crested helmetshrike (*Prionops alberti*) (93%), *Rhinolophus ruwenzorii* (92%), white-striped reed frog (*Hyperolius leucotaenius*) (98), Kivu dwarf litter frog (*Arthroleptis discodactylus*) (98%), Fisher's caecilian (*Boulengerula fischeri*) (100%), and central river frog (*Phrynobatrachus sulfureogularis*) (100%). However, 7 endemic species (Kabobo apalis (*Apalis kaboboensis*), *Balsamocitrus dawei*, Carpenter's chamaeleon (*Kinyongia carpenteri*), Itombwe golden frog (*Chrysobatrachus cupreonitens*), Parker's tree toad (*Laurentophryne*

Table 1
Predicted area of current suitable habitat between taxa and the percentage loss from conversion to agriculture that has already occurred. Globally threatened species are assessed separately.

		Suitable habitat area (km^2)			Loss (%) to habitat conversion		
Status	Taxa (species)	Min	Mean	Max	Min	Mean	Max
Endemic (162 species)							
	Large mammals (4)	317	30,213	117,059	12.6	46.3	81.2
	Small mammals (23)	584	11,880	59,347	1.2	43.6	61.0
	Birds (40)	571	16,731	36,503	2.55	36.2	74.9
	Amphibians (29)	192	14,756	39,154	0.0	31.7	88.1
	Reptiles (11)	886	26,575	66,327	11.6	41.8	54.1
	Plants (49)	296	9,242	40,400	0.26	37.3	56.0
Threatened endemic (38 species)							
	Large mammals (3)	317	39,418	117,059	12.6	46.8	81.2
	Small mammals (4)	1,996	9,578	13,635	32.9	48.7	68.7
	Birds (11)	571	10,803	35,412	6.2	29.5	74.9
	Amphibians (20)	192	11,322	39,154	0.0	23.3	62.5

Table 2
The average percentage of suitable habitat for current and future species predictions within protected areas before 2016 and with the gazetting of Itombwe and Kabobo Massifs as protected areas.

Taxon (species)	Currently		In 2080	
	Mean percentage of current range protected	Mean percentage of range protected after adding Itombwe and Kabobo	Mean percentage of range protected in future	Mean percentage of range protected in future after adding Itombwe and Kabobo
Endemic species				
Birds (40)	26.0	50.8	56.2	71.4
Large mammals (4)	75.2	75.4	77.9	83.2
Small mammals (23)	25.0	33.1	71.7	77.3
Plants (49)	41.7	59.6	62.2	71.3
Reptiles (11)	19.2	28.6	46.2	58.5
Amphibians (29)	14.4	29.3	32.5	50.4
Threatened endemic species				
Birds (11)	30.33	49.8	49.9	68.7
Large mammals (3)	72.1	72.5	71.2	78.3
Amphibians (15)	11.9	30.6	25.4	45.9
Small mammals (4)	31.7	32.7	67.2	67.2

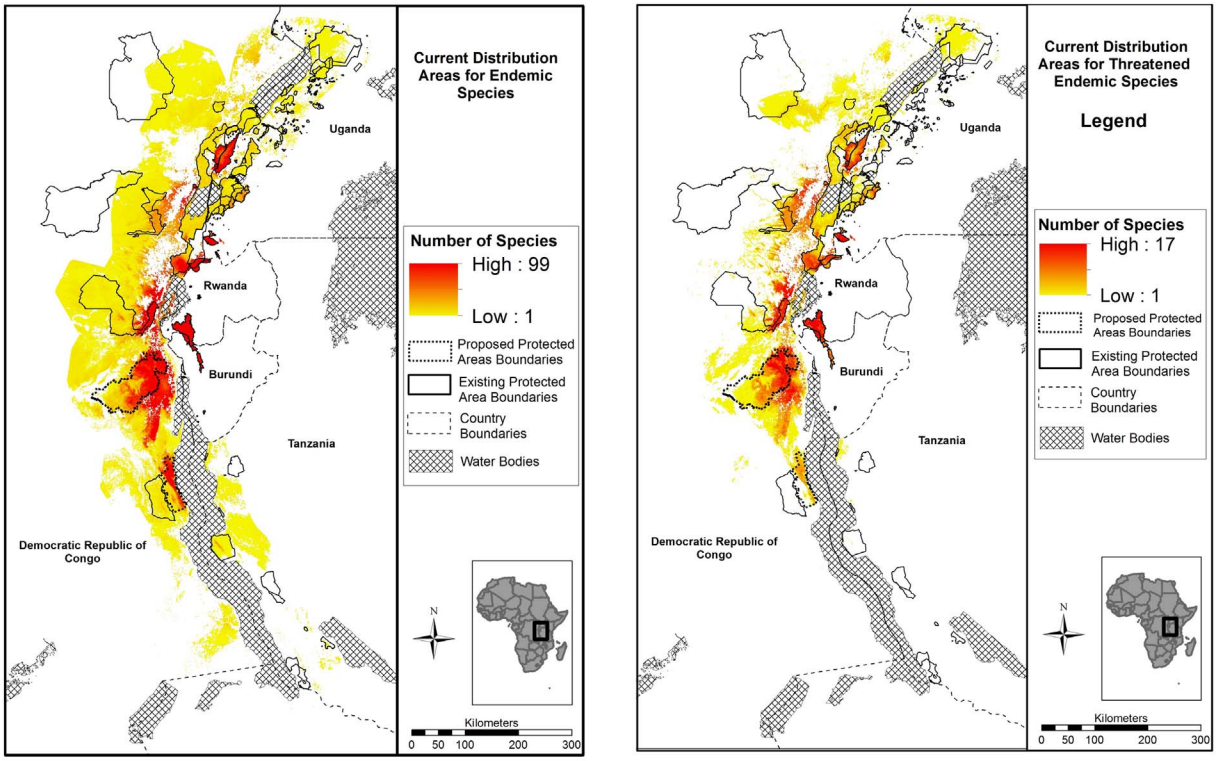

Fig. 1. a) Richness of endemic species (left) and b) threatened endemic species (right).

parkeri), Itombwe river frog (*Phrynobatrachus asper*), and Itombwe massif clawed frog (*Xenopus itombwensis*)) were predicted to experience an increase in their future area of occupancy, with increases in suitable habitat from 3.5% to 139% (See Table S3 in Ayebare et al., 2018).

3.6.2. Estimated suitable habitat in 2070 under CMIP5

On average range contraction under climate change for the twenty birds modelled under the more recent climate models was 80.9% under CMIP3 and 88.9% under CMIP5 (See Table S4 in Ayebare et al., 2018). Of the birds modelled, 17 showed larger habitat loss to climate change by 2070 than the CMIP3 predictions for 2080 (See Table S4 in Ayebare et al., 2018). This indicates that the more recent climate models are showing slightly larger predicted impacts on species but the differences are not great.

3.6.3. Overlap in current and future suitable habitat

There is significant overlap between current and future ranges for most species (Table 3), which means that many species should be able to survive in the areas where they currently occur. Fig. 3a and b show the number of species in each 1 km cell where there is overlap between current species' distributions and projected future distributions. These maps show areas likely to be important as corridors or priority areas for any future gazettment of protected areas in the region. Species with < 30% overlap of their future range with the current range included: Willard's horseshoe bat (0% overlap), golden monkey (*Cercopithecus mitis kandti*) (13% overlap), Carpenter's chamaeleon (26% overlap), *Psychotria palustris* (0% overlap) and Kivu dwarf litter frog (0% overlap) (See Table S3 in Ayebare et al., 2018). These species may need to be targets for assisted migration or special conservation attention.

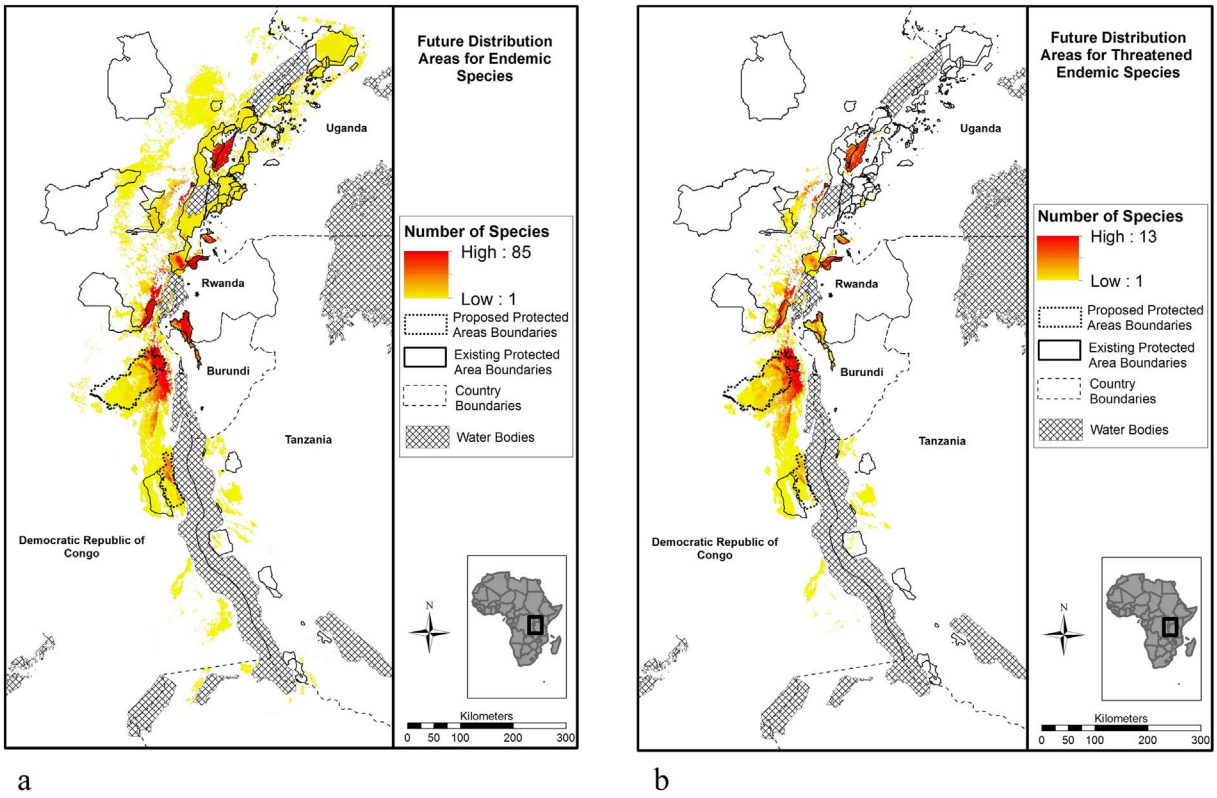

Fig. 2. Predicted richness of a) endemic species (left) and b) threatened endemic species (right) in 2080.

3.7. Extent of species ranges within protected areas in future

The results showed that climate change is likely to increase representation inside protected areas (Table 2). This is because the future area of suitable habitat shrinks but most of this shrinkage is concentrated within existing protected areas at high altitude. The results also showed that conserving the Itombwe and Kabobo massifs significantly increased the percentage of endemic species protected in future, increasing the average current suitable habitat protected from across all species from 30% to 46%, and under future climate from 56% to 68% (See Table S3 in Ayebare et al., 2018).

3.8. Implications of range loss calculations for red listing of species

Calculations of range size and range loss can be used to assess a species Red List status under criteria B and A respectively. Criteria B2 assesses size of AOO and whether the species is declining and number of populations. Criteria A1 and A2 were used to assess inferred decline in populations through reduction in AOO to agriculture over 3 generations or ten years (whichever is greater). As most loss of habitat to agriculture has been over the past 30–50 years this criterion was primarily applied to long-lived species such as trees and some large mammals. Criteria A3 was used to assess Red List status under predicted future suitable habitat loss over 3 generations up to 100 years based on the models as emphasized by Akçakaya et al. (2006). The calculations for each criteria are presented in Table S3 in Ayebare et al., 2018. Currently 34 of the endemic species of the Albertine Rift are listed as globally threatened on the IUCN Red List (IUCN, 2016). Our assessments would increase this to 74 species of the 162 species we have assessed (46% of endemic species). Of these 18 are CR, 24 EN and 32 VU (Table 4).

Table 3
Impact of climate change on average size of predicted range, percentage loss of range to climate change (CC), percentage overlap of the predicted future ranges with current range and average percentage of the overlap regions within protected areas.

		Range size in 2080 (km^2)			Range loss (%) to CC			Overlap of future range with current range (%)	
Status	Taxa(Species)	Min	Mean	Max	Min	Mean	Max	Average percentage overlap	Average percentage protected
Endemic (138 species)									
	Large mammals (4)	51	3,298	12,376	37.5	69.4	89.4	66.4	55.9
	Small mammals (23)	0.0	3,845	19,087	42.4	72.1	100.0	94.1	76.9
	Birds (31)	48	4,506	16,198	51.9	77.9	99.1	85.4	60.9
	Amphibians (22)	0.0	5,744	22,091	7.2	74.6	100.0	83.7	50.1
	Reptiles (11)	1,917	8,201	23,188	55.9	68.1	80.2	91.7	51.1
	Plants (44)	0.0	2,789	9,025	11.7	80.1	100.0	89.6	66.7
Threatened endemic (34 species)									
	Large mammals (3)	51	4,325	12,376	37.5	70.3	89.4	55.3	41.8
	Small mammals (4)	1,087	3,266	7,428	34.8	59.1	92.3	84.9	66.5
	Birds (10)	135	3,097	3,097	54.3	79.2	96.9	78.9	55.3
	Amphibians (17)	0.0	4,105	14,124	7.2	79.9	100.0	76.1	44.8

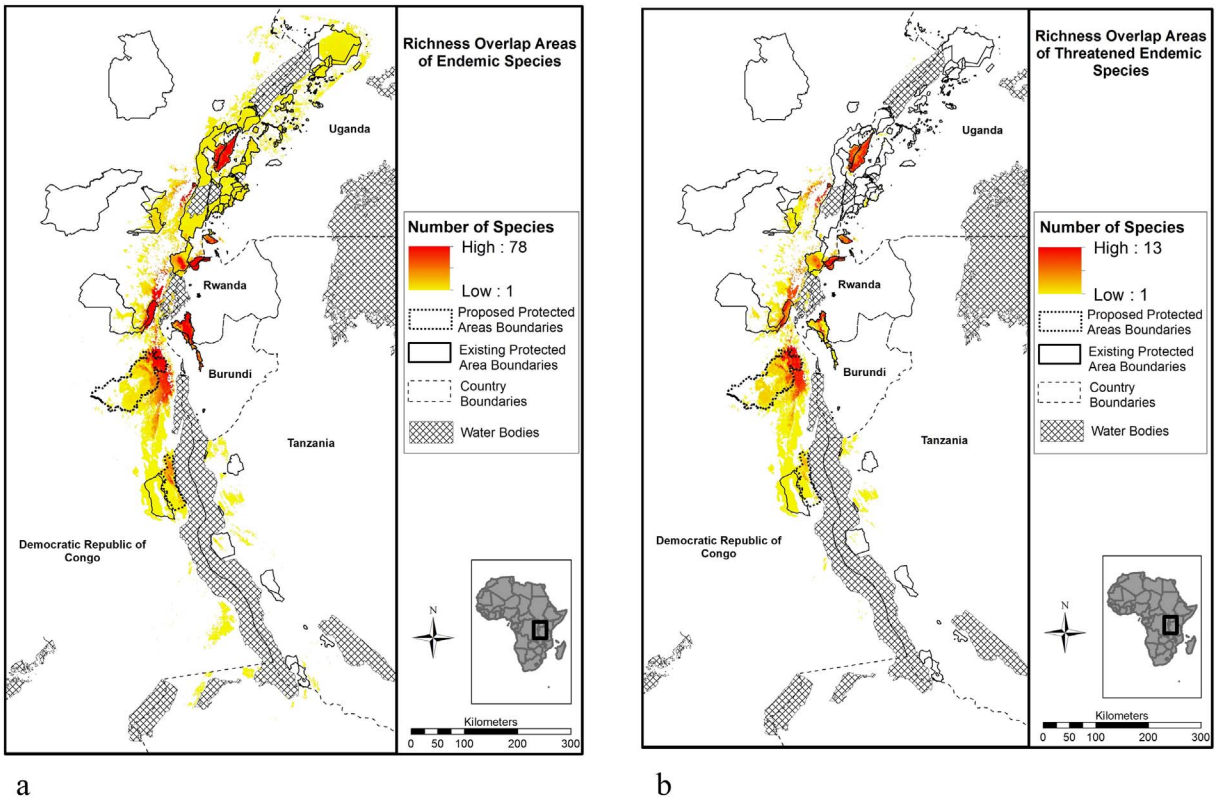

Fig. 3. Numbers of species in overlap areas between current and future ranges for a) endemic species (left) and b) threatened endemic species (right).

Table 4
Estimated number of threatened species applying estimates of range loss to agriculture and predicted loss under climate change over three generations.

Taxon	CR	EN	VU	Total
Amphibian	1	4	9	14
Bird	1	2	8	11
Large mammal	2	2	0	4
Small mammal	13	11	5	29
Plant	1	4	1	6
Reptile	0	1	9	10
Total	18	24	32	74

4. Discussion

4.1. Modelling constraints

Species distribution modelling under future climate change scenarios has its critics (Faye et al., 2014) because of unknown changes in species realized niches that may occur with climate change (Guisan and Thuiller, 2005). Niche models try to predict how species change but depend on coarse climate models that have been downscaled to a 1km^2 resolution using altitude data primarily (Hijmans et al., 2005). Care must be taken when applying such modelling techniques and we accept that our models provide a projection that needs to be tested over time. However, studies that have assessed changes in ranges of species over time with climate change have shown that many species do track their modelled climate niches over time (e.g. birds: Tingley et al., 2009; Trees: Feeley et al., 2010). The method we have used has been applied in many studies (89%) that forecast impacts of climate change (Jones et al., 2016). We believe that as an initial assessment these results are useful and identify species that require monitoring over time to assess whether their niches can adapt to climate changes or whether they will need active conservation action to conserve them.

4.2. Current suitable habitat and impacts of agriculture

We estimated that 30% of the Albertine Rift has already been converted to agriculture because of the high human population densities in this region (Cordeiro et al., 2007). Given the high human population growth rates of 2–3% per year, the pressure for land is likely to lead to future losses. On average the endemic species have lost nearly 40% of suitable habitat to agriculture already and in some species this is as high as 80–90%. The species most affected are in the transition zones between the montane forest and medium altitude forest where the soils and climate are very suitable for agricultural production. Our modelling did not try to predict additional habitat conversion to agriculture in the future, as global models trying to do this are still being developed. Habitat conversion is most likely to occur in eastern DR Congo and pressures on the existing protected areas are likely to increase in Uganda, Rwanda, Burundi and western Tanzania where most montane and medium altitude habitat has already been converted outside protected areas.

4.3. Protection of Albertine Rift endemic species

Protected areas currently conserve on average 45% of the range of endemic species in the region. However, this varies between taxa ranging from an average of only 28% for endemic reptiles and amphibians to 84% for large mammals. The bias reveals that conservation strategies have focused primarily on large mammal conservation in the region. Climate change is likely to restrict species within existing protected areas and we predict that the protected areas are located in areas that will be important for the species under future climate change. The recent gazettment of the Itombwe, Ngandja and Kabobo Reserves in eastern DR Congo significantly increased the protection of endemic species (apart from large mammals) both now and in the future.

4.4. Future climate impacts and conservation

Range contraction under climate change is predicted to be significant for most of the endemic and threatened endemic species of the Albertine Rift using these models (Table 3). Habitat conversion has claimed nearly 40% of the average species range, and forecasts suggest that by 2080, 75% of remaining habitat will be lost. Overlap areas of future ranges with current ranges mostly exceed 30% of the future range (apart from five species) and that on average 63% of these overlap regions are currently protected, indicating that for most species there should not be a need to plan for assisted movement under climate change. We predict therefore, that most of the endemic species found in the Albertine Rift are threatened by future climate change in the long term. Four amphibians, six birds, 19 plants, and five small mammals are of particular concern, as each is predicted to lose > 90% of their current range to climate change (See Table S3 in Ayebare et al., 2018).

Only 34 of these endemic species are currently listed as threatened on the IUCN Red List. Making an assessment of Red List status of all 160 species, using loss of suitable habitat to agriculture or climate change as a proxy for loss of numbers of a species, identified that 46% of the endemic species would qualify for globally threatened status. Each of these species should be monitored closely over time as in future they will likely need to be listed (Akçakaya et al., 2014). The method used for red listing under Criterion A3 can only predict under three generations into the future up to a maximum of 100 years (Akçakaya et al., 2006). Many of the endemic species we assessed do not have long generation times so that we cannot use predicted loss of suitable habitat over the next 65 years in the assessment. However, if the ranges of the species do contract as much as predicted by 2080 then at some point 90% of the species we assessed would meet the A3 criterion for threatened status.

4.5. Planning for future climate change

Although the Albertine Rift is one of the most densely populated areas of Africa (Cordeiro et al., 2007) there are still important sites that warrant conservation consideration. Additional protected areas could be placed around North Balala (along the escarpment above Tanganyika and south of Itombwe Reserve) as the future range of suitable habitat of amphibian species (Itombwe golden frog, Parker's tree toad, Itombwe river frog, Itombwe massif clawed frog) is likely to expand into the area and it also supports a variety of taxa under future climate change (Fig. 2a and b). Similarly improving the protection around the Tayna and Kisimba-Ikobo Reserves will be important for some species such as Grauer's Cuckoo shrike (*Ceblepyris graueri*) that are most common in that region of the Albertine Rift (WCS data).

Species that are predicted to lose all their available habitat include, the recently discovered bat in Kabobo, Willard's horseshoe bat (Kerbis Peterhans et al., 2013), two plants (*Psychotria palustris* found in Nyungwe and Itombwe and *Otiophora pauciflora* found in Nyungwe, Kahuzi, Kabobo and Itombwe), Fisher's caecilian which is only known from the Cyamudongo forest in Rwanda (part of Nyungwe National Park) and the central river frog found in Burundi and the Mahale Mountains in Tanzania. It is likely plans will need to be made to bring these species into captivity or to find suitable habitat where they can be translocated if they are to survive (Guisan et al., 2013; Thomas, 2011).

4.6. Conclusions

Conversion of natural habitat to agriculture in the Albertine Rift has already claimed 38% of the suitable habitat of the average endemic species. Climate change is expected to lead on average to a 75% loss of the remaining range by 2080. The combined impact would mean that on average just 15.5% of species original suitable habitat would remain in 2080. Most of these areas of suitable habitat are predicted to shift upslope in the mountains. On the positive side, there is likely to be significant overlap between the current and future suitable habitat for most species in the region, and nearly 68% of overlapping areas are already protected. This means that for these species the overlap will allow movement to new areas as well as species survival in the existing overlap areas. Thirty one species are predicted to lose all or most suitable habitat by 2080, or do not have any overlap between current and future predicted ranges. These species will need more direct conservation action if they are to be conserved.

Data accessibility information

Data will be made available on the WCS web site-www.albertinerift.org and accessible by request at globaldata@wcs.org once the paper is publishedand is also available as part of the data in brief article associated with this paper (Ayebare et al., 2018).

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